STUDY ON MECHANICAL, THERMAL AND TRIBOLOGICAL BEHAVIOUR OF BAMBOO/PLA POLYMER COMPOSITES DEVELOPED BY ADDITIVE MANUFACTURING TECHNOLOGY

A SYNOPSIS

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1. INTRODUCTION

Polylactic acid (PLA) polymers are extensively utilized as thermoplastic materials that are both biodegradable and compostable. PLA is synthesized from sustainable sources such as corn/rice starch and sugarcanes, and it may be readily broken down into biocompatible chemicals. Furthermore, the PLA sheet materials demonstrate exceptional mechanical and thermal characteristics. Hence, the versatility of PLA continues to expand across diverse sectors, such as biomedical, packaging, automotive, and electronics. Nevertheless, the density of pure PLA is comparatively greater, falling within the range of 1.2 to 1.4 g/cm3. Compared to other thermoplastic polymers, PLA has a comparatively low specific strength. In order to address this problem, it is common to enhance the properties of PLA by including bio-compatible particle fillers or short/long fibres that have a high specific strength. Previous research indicates that the mechanical strength of PLA can be significantly enhanced by reinforcing it with bamboo. Bamboo is frequently strengthened in three different forms: powder, fibres, and woven mats, and is utilized in various technical applications, particularly in the construction industry. Out of these options, it is widely documented that utilizing bamboo in the shape of a woven mat substantially enhances the rate of production and demonstrates superior performance. Therefore, this study chooses a bamboo woven mat as a reinforcement material for PLA.

Various production techniques produce PLA-bamboo composite products, including traditional compression moulding and additive manufacturing. Thin films of pure PLA or PLA-based composite materials are manufactured by subjecting pellets to heat pressing and compression moulding. Injection moulding is utilized for the production of PLA-based goods by employing dried PLA resin. The primary problem with these traditional methods is inadequate adhesion between the PLA and reinforcement. Enhancing adhesion by optimizing traditional manufacturing conditions is a difficult task. To address this problem and produce personalized 3D forms, additive manufacturing (AM) techniques such as fused deposition moulding (FDM) and fused filament fabrication (FFF) have been utilized in recent times. PLA-filler composite filaments are predominantly utilized for material deposition in the additive manufacturing (AM) process. In this study, the FDM method is used to make

bamboo-PLA composite materials by depositing clean PLA onto a bamboo woven mat, rather than directly reinforcing PLA.

Enhancing adhesion while depositing PLA onto the woven bamboo mat is the primary challenge, and it can be addressed by adjusting the FDM process settings. The crucial process parameters for FDM include nozzle temperature, bed temperature, scan speed, and layer height. Out of these parameters, the nozzle temperature has a significant impact on the performance of the additive manufacturing (AM) material. It affects the melting of the filaments and the condition of depositing material. Numerous research in the literature examines the influence of nozzle temperature on the characteristics and efficacy of PLA-based composite materials. Flexural strength is not contingent on nozzle temperature. However, yield strength decreases and then increases with nozzle temperature. PLA-tricalcium phosphate composite material shows constant tensile strength improvement with nozzle temperature. PLA thermal durability and nozzle temperature. The current research needs to be revised because nozzle temperature does not consistently affect characteristics and performance. In addition, there is no individual study that examines the impact of nozzle temperature on different crucial factors of PLA-based composite materials, including microstructure, mechanical and thermal properties, and failure mechanism. Hence, it is exceedingly challenging to arrive at a full conclusion on the impact of nozzle temperature.

At present, 3D printing is extensively employed for extensive customisation on a large scale in the domain of polymer-based composite technology. However, the application of fabric reinforcement has not been thoroughly investigated. Therefore, this study involved the fabrication of composite laminates employing B fabric as the reinforcing material and thermoplastic PLA as the matrix, utilizing additive manufacturing (AM) technology. The manufacturing process of bamboo-PLA composite material is established in two parts. The process begins by applying PLA onto the bamboo mat to form thin sheets, which are then joined together using hot compression moulding. A comprehensive investigation is conducted to analyse the impact of nozzle temperature on the mechanical and thermal properties, as well as the microstructures, of bamboo-PLA composite material as in Figure 1. In addition, a comprehensive characterization investigation was conducted utilizing FTIR, XRD,

and SEM techniques to provide insight into the chemical compositions, structural alterations, and topography of the cracked surface. The results demonstrated that increasing the nozzle temperature consistently improves the mechanical and thermal properties. This is attributed to the higher interfacial adhesion resulting from the contact between the polymer and the fabric reinforcement.

2. LITERATURE REVIEW

This chapter provides a detailed analysis of the previous research conducted in the subject of natural fibre reinforced polymer composites. These literature reviews provide important information on natural fibre composites for meeting our sustainable needs. This chapter included polymer matrix composite mechanical properties (tensile, flexural, and impact), material characterization, thermal behaviour, and tribology. This section analyses previous research and publications by researchers.

Matsuzaki et al. [1] highlighted the potential of three-dimensional printing of continuous-fibre composites by in-nozzle impregnation. This approach demonstrates the capability of integrating natural fibres into composite materials using advanced manufacturing techniques.

Girijappa et al. [2] provided a comprehensive review of natural fibres as sustainable and renewable resources for the development of eco-friendly composites. Their work emphasized the importance of leveraging natural fibres to enhance the sustainability and environmental friendliness of composite materials.

Nagarajan et al. [3] emphasizes the importance of toughness and heat resistance in PLA-based sustainable materials for durable applications. The authors provide a comprehensive perspective on the properties of PLA composites, highlighting their potential for various applications.

Mukherjee and Kao [4] PLA-PHB blends have been identified as interesting for the controlled release of active compounds in the development of active packaging systems.

Zhang et al. [5] investigated the effect of different NaOH solutions on bamboo fibre treatments and concluded that 6 wt. % NaOH treated bamboo fibres were optimal

for the fabrication of bamboo fibre composites. This finding suggests that the chemical treatment of bamboo fibres plays a crucial role in enhancing the properties of the resulting composites.

Muhammad et al. [6] highlighted that bamboo fibres have good mechanical properties and better fibre and matrix interaction, resulting in good interfacial adhesion between fibre/matrix and fewer voids in the composite. Additionally, the use of coupling agents, such as maleic anhydride polypropylene (MAPP), was found to improve the adhesion of bamboo fibres in the polypropylene (PP) matrix, further enhancing the overall mechanical performance of the composites.

Wang et al. [7] reviewed the mechanism and performance of 3D printing for continuous fibre-reinforced thermoplastic composites. They emphasized the need to explore the impact of printing parameters on the resulting mechanical properties of the printed parts.

Goh et al. [8] discussed recent progress in additive manufacturing of fibre-reinforced polymer composites and highlighted the importance of minimizing these defects. The presence of voids and poor bonding can compromise the strength and durability of printed parts, highlighting the need for effective treatment methods.

Feng et al. [9] investigated the fabrication of LDPE/nanocellulose composites using an organic solvent-free process. The results showed that this method can lead to composites with improved mechanical properties. The study also highlighted the scalability of the process to industrial production scale. This finding is significant as it suggests that hot compression moulding can be a viable method for large-scale production of composites with enhanced mechanical properties.

Han et al. [10] provides valuable insights into the potential of hot compression moulding for fabricating composites. However, there are still knowledge gaps that warrant further investigation. For instance, while the study demonstrated the improved mechanical properties of the composites, the specific mechanisms underlying these enhancements were not fully explored. Future research could focus on elucidating the microstructural changes and interfacial interactions that contribute to the improved mechanical properties of the composites.

Gujjala et al. [11] evaluated the mechanical properties of woven jute-glass hybrid-reinforced epoxy composites and reported that the polylactic acid/sisal composite exhibited superior mechanical properties.

Charlet et al. [12] examined the mechanical properties of flax fibres and their derived unidirectional composites, providing valuable insights into the mechanical behaviour of natural fibre-reinforced composites.

El-Shekeil et al. [13] investigated the influence of fibre content on the mechanical, morphological, and thermal properties of kenaf fibres reinforced poly (vinyl chloride)/thermoplastic polyurethane poly-blend composites. The authors emphasized the significance of thermal assessments of the composite properties and its ability to replace traditional petroleum-based materials.

Essabir et al. [14] explored the structural, mechanical, and thermal properties of bio-based hybrid composites from waste coir residues, including fibres and shell particles. The study provided insights into the thermal properties, classification, functionality, and different processing methods for natural thermoplastic composites.

Athith et al. [15] investigated the effect of tungsten carbide on the mechanical and tribological properties of jute/sisal/E-glass fabrics reinforced natural rubber/epoxy composites. The study demonstrated that the addition of tungsten carbide particles significantly improved the wear resistance of the composites, leading to reduced friction and enhanced mechanical durability. This finding indicates the potential of incorporating hard particles as reinforcements to enhance the wear performance of natural fibre composites.

Alsubari et al. [16] provided a comprehensive review of the mechanical properties of natural fibre-reinforced polymer composites in sandwich structures. The study highlighted the potential of natural fibre composites in sandwich structures and examined their mechanical properties under various compression loads. However, the review did not specifically address the dry sand abrasive test, indicating a knowledge gap in evaluating the abrasive resistance of natural fibre composites.

3. RESRARCH GAP

- A few studies in the literature discuss the role of nozzle temperature on the properties and performance of PLA-based composite materials.
- 3D printing is widely used for the large scale customization in the field of polymer based composite technology, the utilization of reinforcement in the form of fabric not yet explored well.
- The effects of nozzle temperature on PLA-based composite materials' microstructure, mechanical, thermal, and failure mechanisms have not been studied. Nozzle temperature's inconsistent effect on characteristics and performance is the main issue with the literature.

4. OBJECTIVE

The following objectives were deduced from the research gap.

- To fabricate the biopolymer prepreg composites using bamboo fabric and PLA filament in FDM process.
- To develop the bamboo/PLA composites using FDM followed by hot compression moulding techniques (synergistic manufacturing technique).
- To investigate mechanical properties such as tensile, flexural, impact, and hardness of bamboo/PLA composite samples.
- To characterize the wettability behaviour of bamboo/PLA composite samples using contact angle measurement.
- To investigate the thermal behaviour of bamboo/PLA composite samples.
- To investigate the tribological behaviour of PLA, bamboo and bamboo/PLA composite samples using dry sand abrasive wear test.
- To investigate the adhesion between fibres and the matrix, as well as the occurrence of voids, debonding, and other interfacial phenomena examined using a scanning electron microscope

5. METHODOLOGY

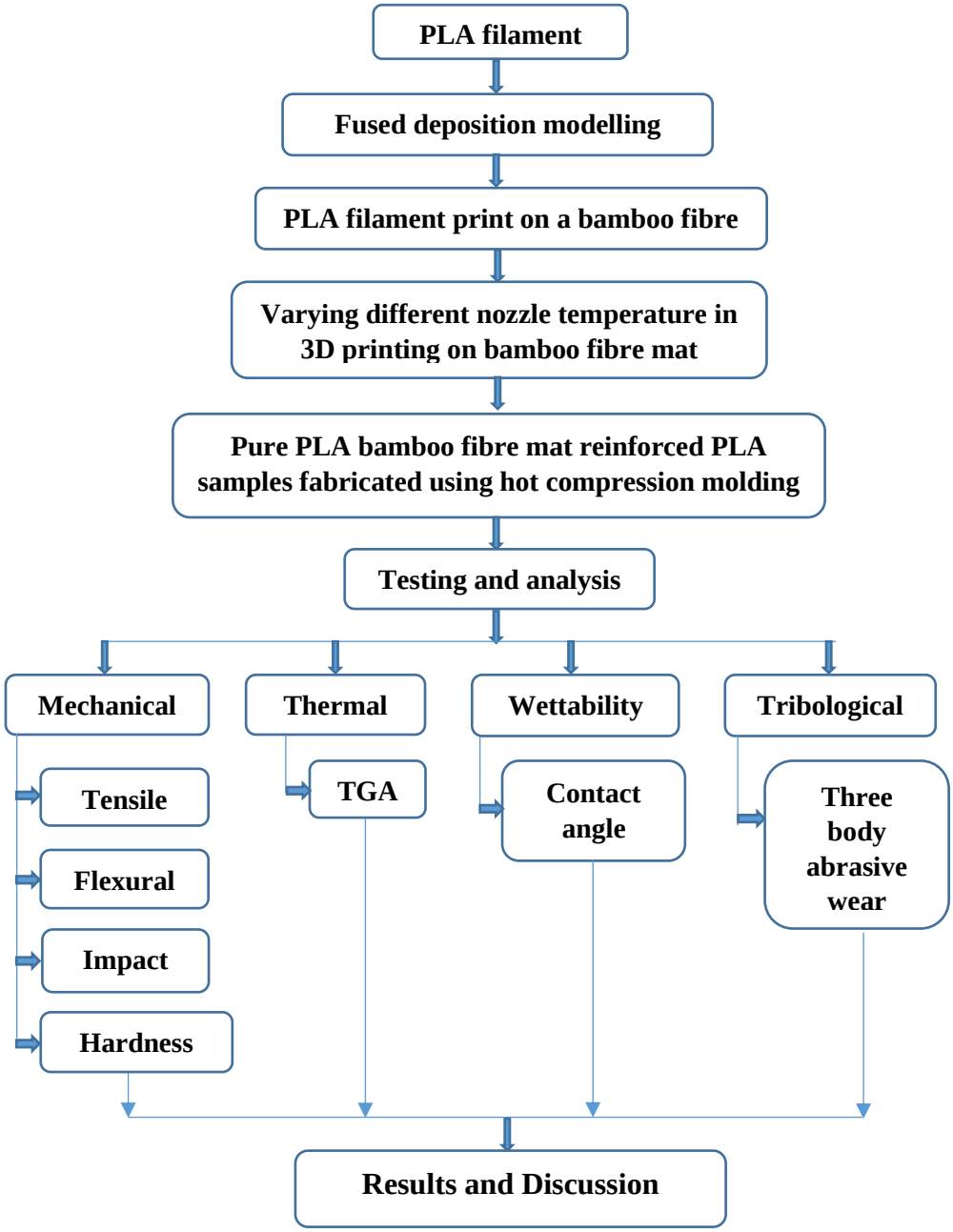

Figure 1 Research Methodology for bamboo/PLA composites

6. RESULT AND DISCUSSION

6.1. Physical properties

The mass density of B-PLA was determined at different FDM nozzle temperatures using the Archimedes principle. This was done to get insight into how the reinforcement is packaged within the polymer matrix. The Figure 2 displays the mass density of pure PLA and bamboo fibres for comparison. The density of the B-PLA composite falls within the range of densities of the PLA matrix and the bamboo

fibre reinforcement, as anticipated. Furthermore, the bulk density of the B-PLA composite slightly rises when the FDM nozzle temperature, T_{FDM}, increases. For example, the mass density increases from 1.15 g/cm3 to 1.26 g/cm3 when the temperature of the T_{FDM} increases from 195°C to 245°C. The observed rise in mass density can be linked to the following two microstructural traits of the B-PLA composite. (i) The rise in T_{FDM} leads to a corresponding increase in the temperature of molten PLA, hence enhancing its flow ability. Consequently, the PLA is noted to evenly disperse while having smaller openings. (ii) Furthermore, the rise in T_{FDM} also subjects the bamboo mats to elevated temperatures. It modifies the condition of the bamboo mat in a localized manner, leading to enhanced adhesion with PLA over time. The confirmation of these two points is achieved by conducting a microstructural analysis of the manufactured materials.

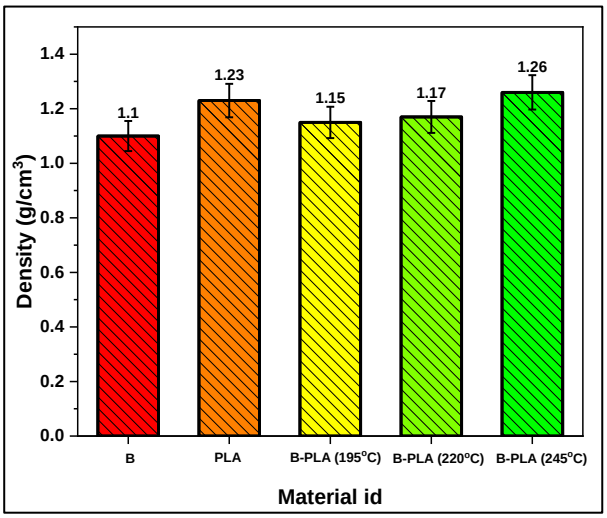

Figure 2 Measured mass density of B-PLA composites for various FDM nozzle temperatures

6.2. Contact Angle

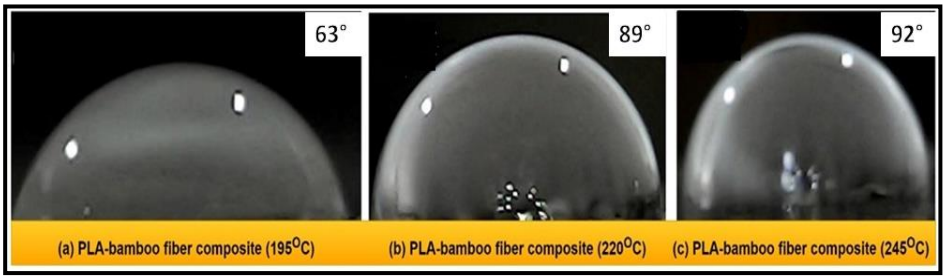

Figure 3 Contact angle tested specimens (a) B-PLA 195°C (b) B-PLA 220°C (c) B-PLA 245°C

The surface of the PLA-bamboo fibre composite, which was produced via 3D printing at a temperature of 195°C and compression molding, exhibited a hydrophilic character with a contact angle of 63°. This can be attributed to the combination of minimal surface roughness and strong interaction between the surface and water molecules. On the other hand, the PLA-bamboo fibre composite at temperatures of 220°C and 245°C exhibited contact angles of θ=89° and θ=92° respectively, as a result of eliminating the largest pores and hydroxyl functional groups. By subjecting PLA to its maximum temperature during 3D printing, the cavity holes and hydroxyl functional groups are eliminated, resulting in a decrease in the interaction between water molecules. Consequently, the PLA-bamboo fibre composite surfaces generated at temperatures of 220°C and 245°C exhibited an increase in surface roughness and demonstrated hydrophobic characteristics. The PLA-bamboo fibre composites, generated through covalent bonding and having hydrophobic qualities, exhibit favorable mechanical and thermal characteristics when subjected to temperatures of 220°C and 245°C. This observation is also depicted in Figure 3.

6.3. XRD

The X-ray diffraction (XRD) patterns of B-PLA composites with different thermally functionalized dispersing agents (T_{FDM}) were measured, along with pure PLA. The traditional Segal approach, as described by Segal et al in 1959, is used to determine the modulation of 2-theta intensity. The PLA sample has a crystallinity of 22.1%, as evidenced by the presence of peaks at 16.65° and 22.8° shown in figure 4. Additionally, B-PLA exhibits a greater degree of crystallinity compared to pure PLA.B-PLA with a thermal decomposition temperature (T_{FDM}) of 195°C has an additional peak at 27.4° compared to pure PLA.

The three peaks result in a crystallinity of 52.3%. Additional low-intensity peaks in the Figure 4 may not possess a specific crystal orientation and are hence not taken into consideration. At temperatures of 220°C and 245°C, there is a significant overlap of crystalline peaks. The projected degree of crystallinity for samples heated to 220°C and 245°C is 65.9% and 70.3%, respectively. The level of crystallinity rises as the temperature of the FDM nozzle increases.

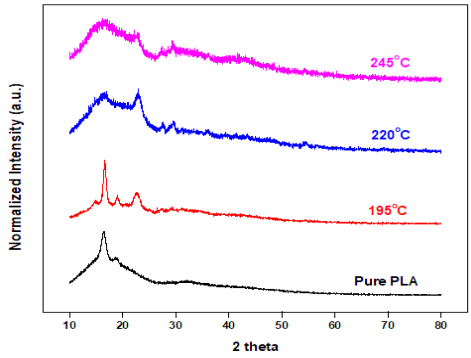

Figure 4 B-PLA composites and pure PLA XRD patterns for all three-nozzle temperature (T_{FDM})

6.4. FTIR

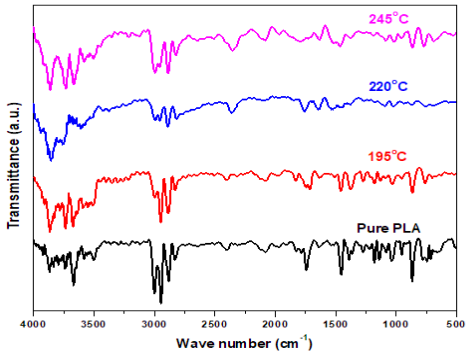

Figure 5 FTIR spectrum of B-PLA composites various T_{FDM}

Figure 5 displays the FTIR patterns of the three B-PLA composites, as well as the plain PLA matrix. The spectra of all four samples span from 500 to 4000 cm-1, with a few distinct absorption peaks. The functional groups corresponding to the discovered absorption peaks are labelled according to the standard infrared spectrum table. The key functional groups observed in neat-PLA are as follows: (1) medium/O-H stretching/alcohol (3668 cm-1); (2) strong/O-H stretching/carboxylic acid (3000 cm-1); (3) medium/C-H stretching/alkene (2943 and 2879 cm-1); (4) strong/C-O stretching/aldehyde (1743 cm-1); (5) medium/C-H bending/alkene (1450 cm-1); and (6) strong/C-C bending/alkene (866 cm-1). The low wave number functional groups, such as strong/C-C bending/alkene, medium/C-H bending/alkene, and strong/C-O stretching/aldehyde, that are seen in clean PLA are absent in the B-PLA composites. Simultaneously, two more peaks are detected, which correspond to the medium/O-H stretching/alcohol functional group, at approximately 3730 and 3860 cm^{-1} wave numbers.

6.5. Vicat Softening Testing

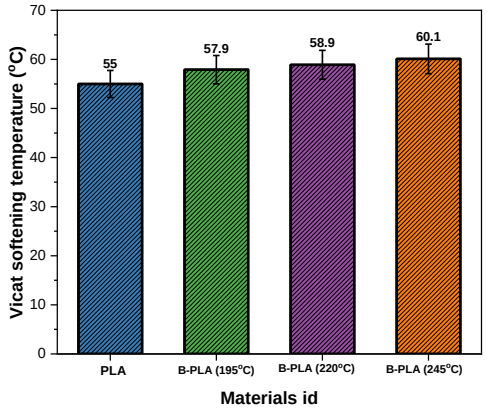

Figure 6 Vicat softening temperature

Figure 6 displays the measured VST for B-PLA composites, as well as the value for plain PLA. The VST value for pure PLA is obtained directly from the specs provided by 3D crafts, Madurai, for their PLA filament. Due to the reinforcing properties of the bamboo mat, the composite materials exhibit greater values of VST (Vicat Softening Temperature) in comparison to pure PLA (Polylactic Acid). Moreover, the measurement demonstrates a direct linear relationship between the increase in T_{FDM} and the increase in VST. This correlation can also be attributed to the bonding of bamboo fibre with PLA. The heat distortion temperature is determined using VST testing to assess the thermal stability of a material.

The ASTM D1525 standard specifies that the Vicat Softening Temperature (VST) test is conducted with a 10N load in an oil bath that is heated at a rate of 120°C per hour until a 1mm penetration is achieved. Therefore, the material undergoes a softening process at the VST (Vicat Softening Temperature). The use of bamboo mats in the composite materials enhances its VST values, surpassing those of clean PLA. The figure displays the measured values of the VST (Vicat Softening Temperature) for the B-PLA composite and clean PLA. The precise PLA VST value is derived from the 3D craftsmanship and the specific specifications of the Madurai PLA filament. The measurement also indicates a direct correlation between T_{FDM} and the increase in VST, which is linked to the bonding between bamboo fibre and PLA. The use of T_{FDM} enhances interface bonding, increasing the temperature required to achieve a specific depth under a constant load.

6.6. TGA

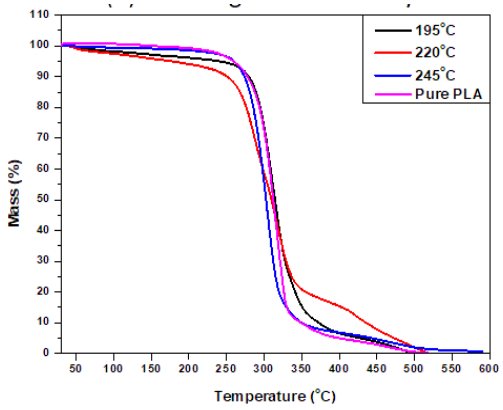

Figure 7 Thermogravimetric profiles of B-PLA composites and pure PLA

TGA curves of B-PLA composites for various T_{FDM} are shown in Figure 7 together with clean PLA. Water molecules and volatile chemical compounds are known to be present in polymeric materials made with natural fibres. Before the material begins to decompose, these chemicals usually evaporate during the sample's first heating. As illustrated in Figure 7, this effect is evident in the temperature range of 30°C to approximately 250°C and is also detected in the current investigation. Both plain PLA and B-PLA composite show a rapid mass loss beyond ~250°C.

According to reports, at this point, the carbon-carbon and carbon-hydrogen linkages in the PLA matrix and bamboo fibre will break down. With TFDM of 195°C, 220°C, and 245°C, the temperature corresponding to maximal material loss is determined to be 314°C, 317°C, and 303°C using the derivatives of the TGA profile. 317°C is a comparable temperature for the maximum mass loss in tidy PLA. Furthermore, it can be inferred from the TGA profiles that residue is not left behind at temperatures higher than about 500°C for either neat PLA or B-PLA composite. The fact that there is just one weight-loss peak visible in the B-PLA TGA curves indicates that there was no phase separation between PLA and bamboo. Overall, the TGA analysis indicates that there are not enough differences between the neat PLA and B-PLA degradation temperatures and mass loss profiles for different TFDM to require consideration.

6.7. Mechanical test

6.7.1. Tensile test

B-PLA tensile stress-strain curves for various T_{FDM} are shown in Figure 8 (a). Both 220°C and 245°C T_{FDM} samples were considered. Only the stress-strain curves till failure are displayed here. The tensile curves in figure 8(a) show that T_{FDM} strengthens composites. Sample ductility is inconsistent. Importantly, T_{FDM}=245°C samples vary greatly in ductility. No variation in strength levels. Figure 8 (b) shows the ultimate strength of B-PLA for varied T_{FDM}, neat PLA, and bamboo fibre. The ultimate strength of B-PLA composites lies between neat PLA and bamboo fibre, as expected and supported by the literature. Further, T_{FDM} may increase strength by reducing porosity and improving bamboo mat-PLA matrix bonding. A higher nozzle temperature raises molten PLA's temperature, improving flow ability. It reduces PLA pores and distributes evenly. Further, raising the nozzle temperature raises the bamboo mats' temperature, improving PLA adhesion. These two factors improve nozzle temperature-induced tensile strength.

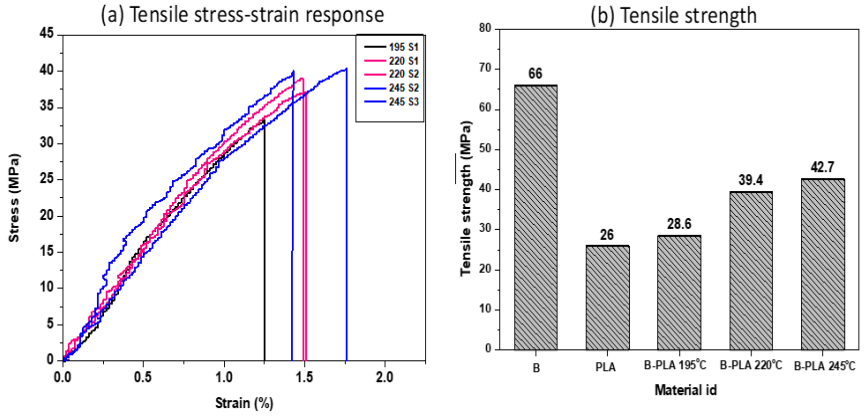

Figure 8 (a) Measured tensile stress-strain curves of B-PLA. Two samples were considered for T_{FDM} =220°C and 245°C. (b) The ultimate tensile strengths of pure PLA, bamboo fibre and B-PLA for different T_{FDM}

In Figures 9(b), (c), and (d), the fracture surface SEM images for materials with T_{FDM}=195°C, 220°C, and 245°C are displayed. In the centre row, scans of the entire thickness all three PLA bamboo sheets cover the failure surface. To show the PLA-bamboo interface after failure, the top and bottom rows magnify small portions. Important findings include: PLA-bamboo sheets are bonded until fracture without delamination. The compression moulding method appears to bind AM PLA-bamboo

sheets without flaws. The fracture surface has normal-loading bamboo fibres. Crack propagation dissolves PLA-bamboo fibre interface cohesiveness without damaging the fibre. The loading axis-parallel bamboo fibres break. Considering the tensile strength of neat PLA and bamboo fibre in Figure 9, fibre breakage may be the failure mechanism. In this material, fibre breakage is the rate-limiting damage process.

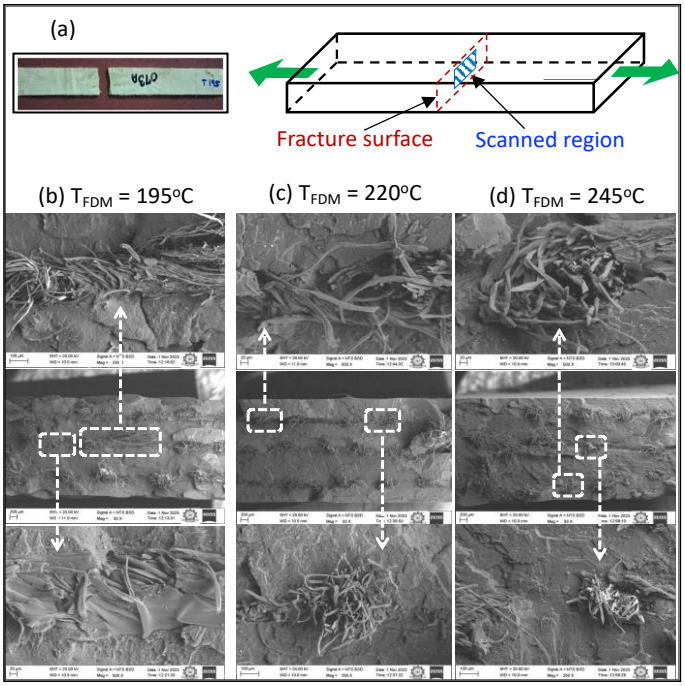

Figure 9 (a) Sample failure and schematic of scanned surface. T_{FDM} of (b) 195°C, (c) 220°C, and (d) 245°C microstructural characterisation of tensile sample fracture surfaces. Various rows represent failed surface magnifications

6.7.2. Flexural test

The ultimate flexural strength of all three B-PLA samples and tidy PLA is illustrated in Figure 10(a). Bamboo fibre additionally increases composite material flexural strength. As expected, B-PLA has higher flexural strengths than plain PLA and rise with T_{FDM}. Figure 10(b) depicts a failed sample. Figure 10(b) shows microstructural study of the fracture surface-centered front region. This surface can indicate the bending sample's tensile and compressive areas and, most critically, crack morphology and propagation direction. Figures 10(c), (d), and (e) show SEM images of the targeted region for samples with T_{FDM}= 195°C, 220°C, and 245°C. First, like the tensile test, PLA-bamboo sheets do not delaminate, and all three samples fail similarly. Second, the failure remains on the top tensile side till the neutral axis, as

expected. No compression cracking is visible. Third, cracks propagate inside the PLA matrix and along the PLA-bamboo contact. The center top image depicts bamboo fibre breakdown parallel to the sample's long axis or tensile direction.

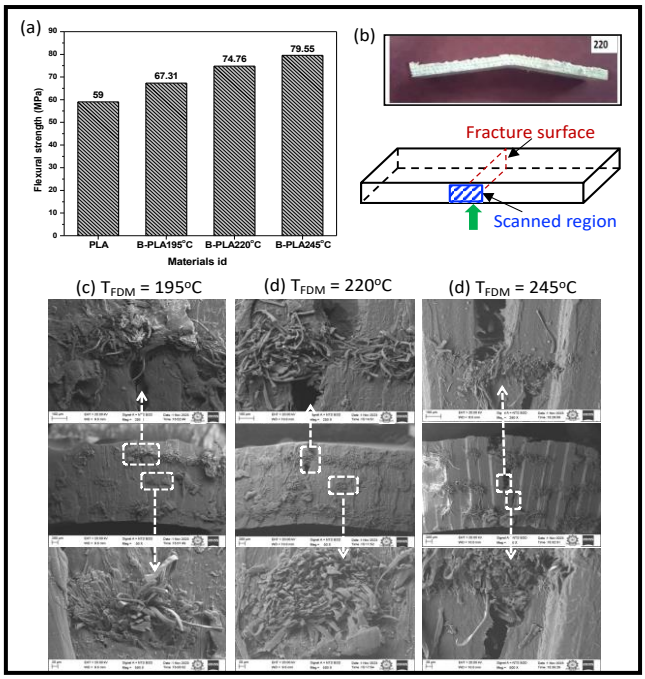

Figure 10 (a) B-PLA composites and neat PLA flexural strengths were measured (b) Schematic of a failed flexural sample's scanning surface *(*c) Microstructural characterization of the failure region

6.7.3. Impact test

B-PLA composite impact tests follow ASTM D 256 without notches. This uses the Instron CEAST pendulum impact instrument with a 1J hammer. We cut samples into 64 X 12.7 X 3 mm strips for impact testing. Figure 11(a) shows B-PLA impact strengths and neat PLA value. Unlike tensile and flexural tests, B-PLA has a similar impact strength to plain PLA. Figure 11(b) shows SEM pictures of the fracture surface, as in earlier occurrences. Figures 11(c), (d), and (e) demonstrate B-PLA composite material microstructural pictures with similar fracture behavior. Thus, even under impact pressure, the fracture surface decohesion of PLA and bamboo fibres and the breakage of bamboo fibres normal to the fracture surface cause failure.

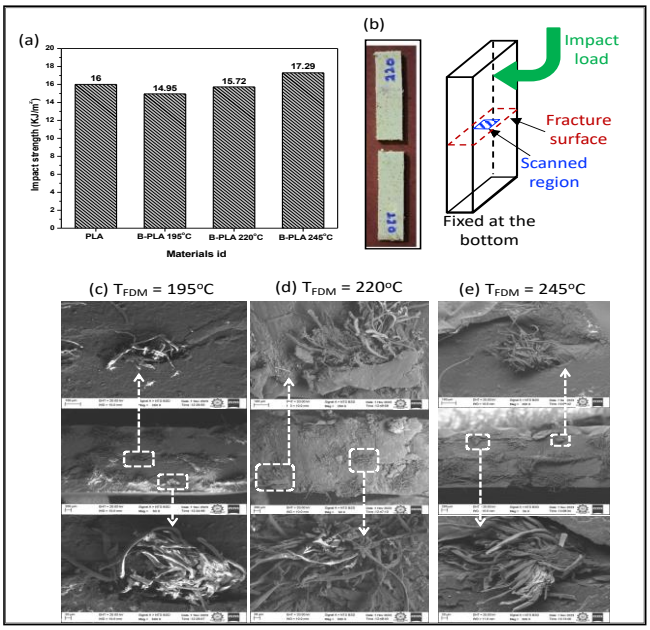

Figure 11 (a) Impact strengths of B-PLA composite with various nozzle temperatures and neat PLA. (b) Broken impact test sample with schematic to show the SEM scanning region (c) (d) (e) Fractography of impact test samples at different nozzle temperatures

6.7.4. Hardness

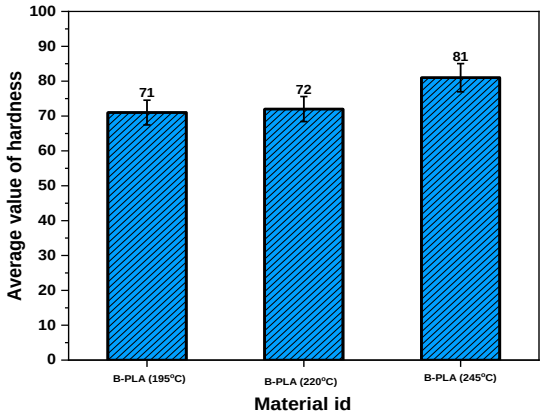

Figure 12 Average hardness value of B-PLA composites

A shore D hardness durometer was used to conduct the test for hardness in accordance with ASTM D785. The micro hardness test is used to investigate the surface hardness of the samples that have been manufactured. 71, 72 and 81 for 195°C, 220°C and 245°C respectively are the results of this outcome shown in Figure 12. Along the same lines as other mechanical qualities, the surface hardness of the nozzle increases as the temperature rises. An increase in the temperature of the nozzle results in an increase in the flow of melt and the matrix material wetting of reinforcing fibres such as bamboo. The fibre-matrix interfacial bonding may be promoted as a result, leading to an increase in composite hardness.

7. ORGANIZATION OF THESIS

Chapter 1: This chapter presents a comprehensive overview of composites, including the classification of composite materials and their uses in diverse industries such as aerospace, marine, automotive, construction and building, electronics, and medicine. The article also covers the topic of bamboo-reinforced composites, which are a type of thermoplastic composite material reinforced with natural fibres. It explores the importance of using bamboo fibres in thermoplastic composites and discusses hybrid manufacturing procedures.

Chapter 2: This chapter examines new literature studies that focus on the mechanical, thermal, and tribological characteristics of composites made from thermoplastic materials reinforced with bamboo fibres. A comprehensive examination of fabrication techniques, such as 3D printing, hot compression, and hybrid manufacturing, has been conducted in the literature study. In addition, the research methodology and the research gap are outlined. This chapter also includes the research objectives.

Chapter 3: This chapter presents investigation on the characteristics of bamboo treated and untreated fibre. The tensile and elongation study were discussed and also this chapter also discusses the FTIR, XRD and thermal characteristics. In addition, a scanning electron microscopy (SEM) analysis was performed to investigate the bamboo fibre that underwent treatment as well as the untreated bamboo fibre.

Chapter 4: This chapter presents comprehensive information on the characteristics of the fibres and matrix material, as well as the meticulous process of preparing samples. The approach for fabricating using a synergistic manufacturing technique is described. This chapter provides the testing procedures and standards for each specific test.

Chapter 5: This chapter focuses on conducting mechanical characterisation investigations, including tensile analysis, flexural analysis, impact analysis, and hardness study. This chapter also discusses the wettability investigation of the

BF/PLA fibre reinforced composite samples, which includes contact angle testing. Additionally, a scanning electron microscopy (SEM) study was conducted to examine the broken specimen of the mechanically tested composites.

Chapter 6: This chapter discusses thermal characterisation experiments, specifically focusing on thermogravimetric analysis (TGA) of BF/PLA fibre reinforced composite samples. This chapter focuses on the tribological characterisation research of dry sand abrasive wear analysis for BF/PLA fibre reinforced composite samples. Scanning Electron Microscopy (SEM) investigation was conducted to examine the cracked specimen of the worn-out composite samples.

Chapter 7: This chapter presents the research conclusions based on the findings, and offers potential future scope for this research.

8. REFERENCE

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9. LIST OF PUBLICATIONS

1. **Suresh Sethu**, Mayandi Kalimuthu, Rajini Nagarajan, Kumar Krishnan, Faruq Mohammad, Mariyappan Arul Kumar, Hybrid fabrication and characterization of biocompatible Bamboo/PLA composites, *Journal of Materials Research and Technology/Journal of Materials Research and Technology*, **29** (2024), 2656-2666.
2. **Suresh Sethu**, Mayandi Kalimuthu, Rajini Nagarajan, Sikiru O Ismail, Kanniga Devi, M Muthukannan, M Murali, Faruq Mohammad, Hamad A Al-Lohedan**,** Thermal, chemical, tensile and morphological characterization studies of bamboo fibre extracted from the indian species bambusa bambos, *Materials Research Express*, **10** (10) (2023),105501.
3. **Suresh Sethu**, Mayandi Kalimuthu, Rajini Nagarajan, K Devi, M Muthukannan, M Murali, Characterization on a physical and mechanical bamboo surface treated and untreated fiber, *AIP Conference Proceedings*, (2023).